Stabilization of the line-tied resistive wall mode by a rotating conducting wall

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G. Fiksel, C.C. Hegna, J.S. Sarff, C.B. Forest

MHD Control Workshop 2011, Madison, WI

**Tour of experiment
Will be Tuesday, 6pm**

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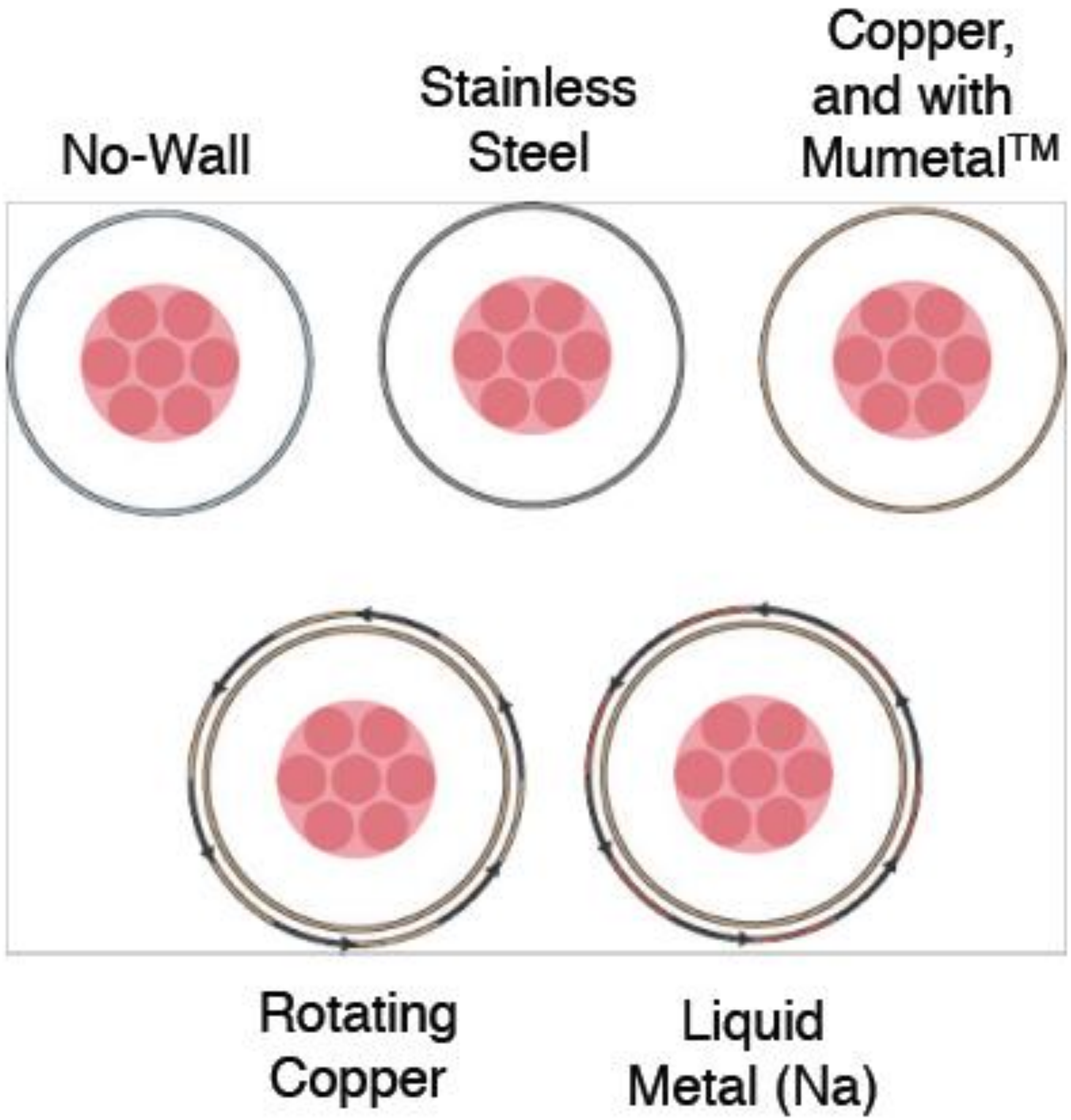
Experiment Studies MHD Under Variable Electromagnetic Boundary Conditions



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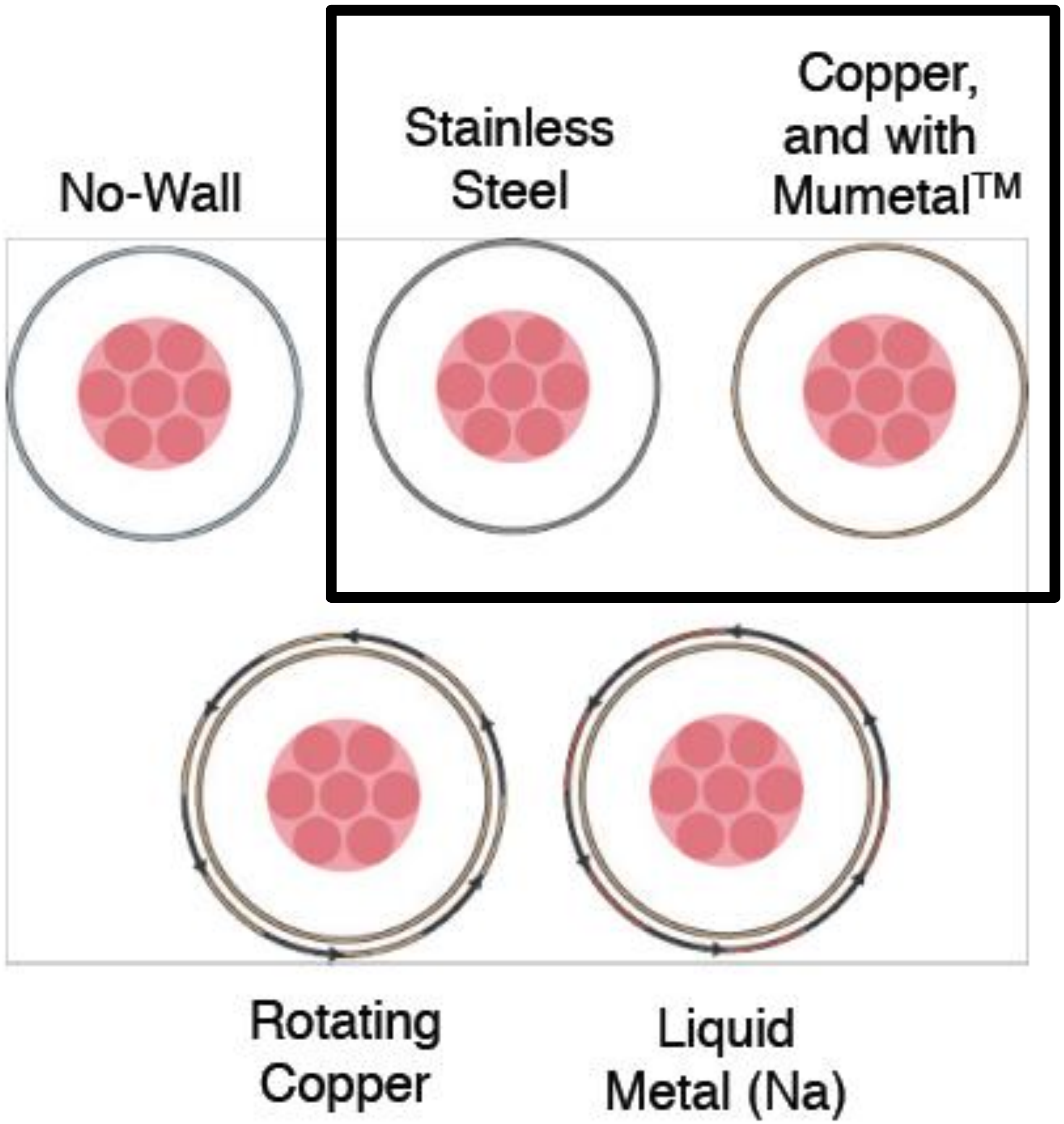
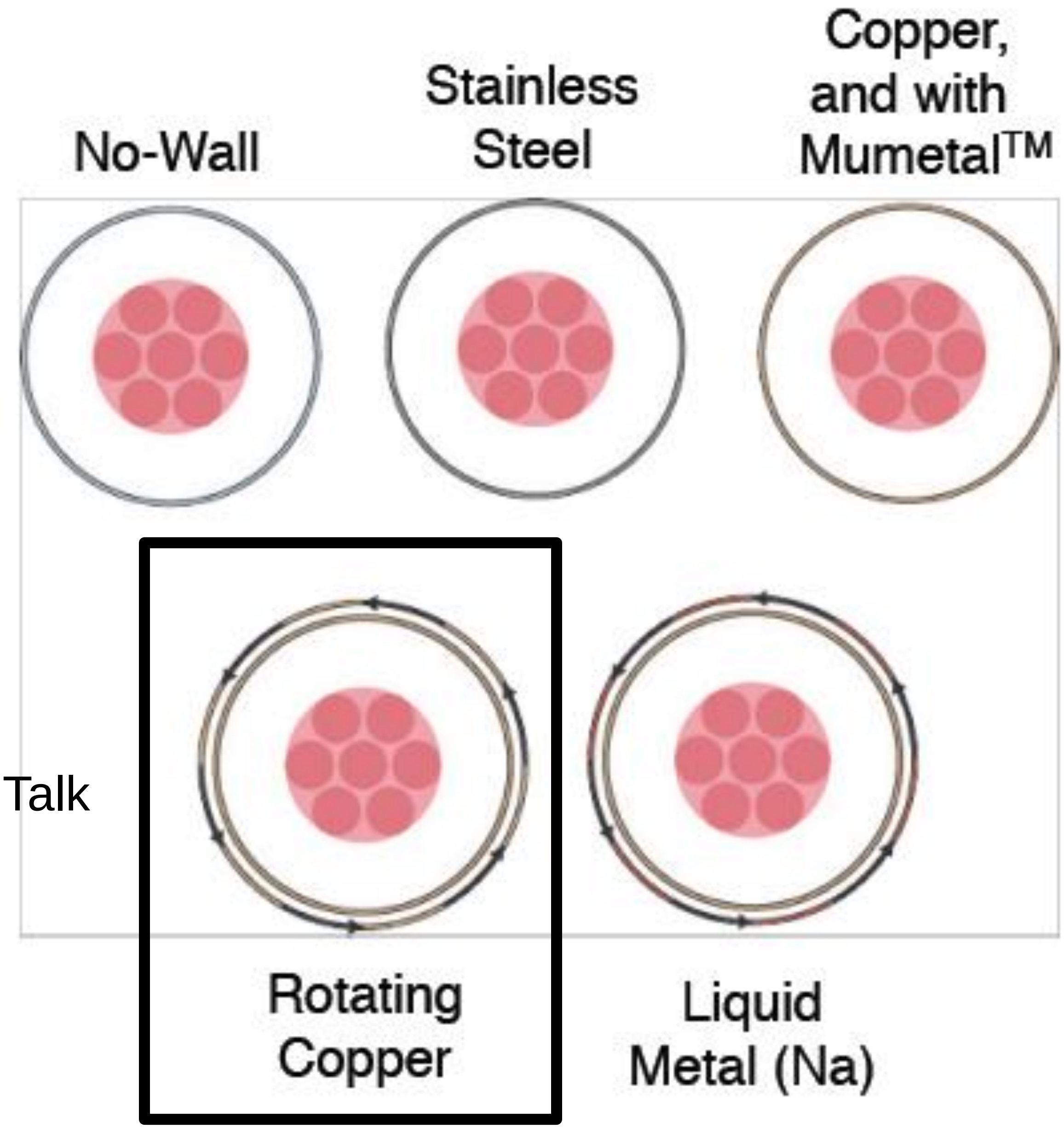


Last Talk (2008)
J.S. Sarff,
W.F. Bergerson
et al

Experiment Studies MHD Under Variable Electromagnetic Boundary Conditions

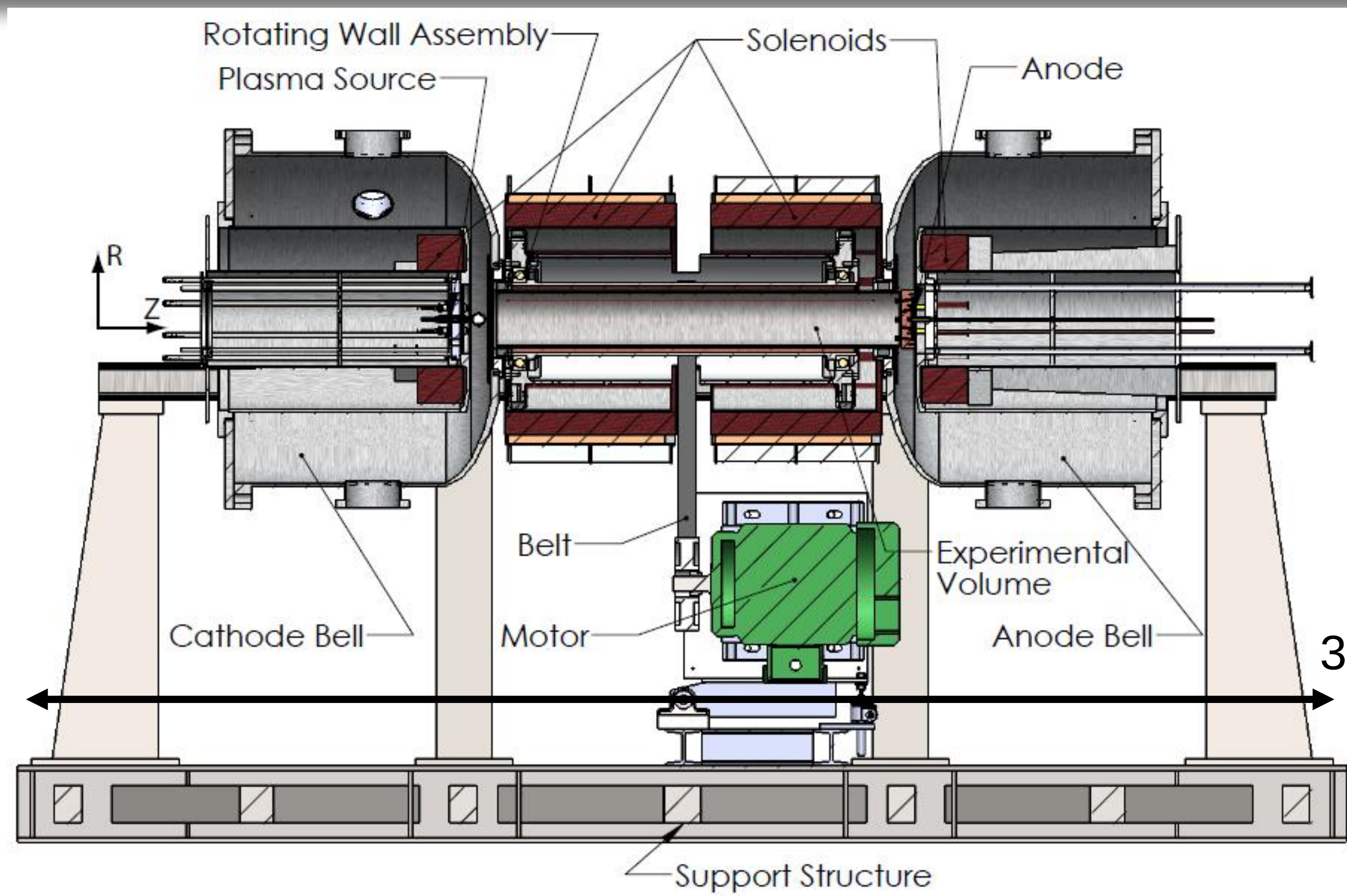


This Talk

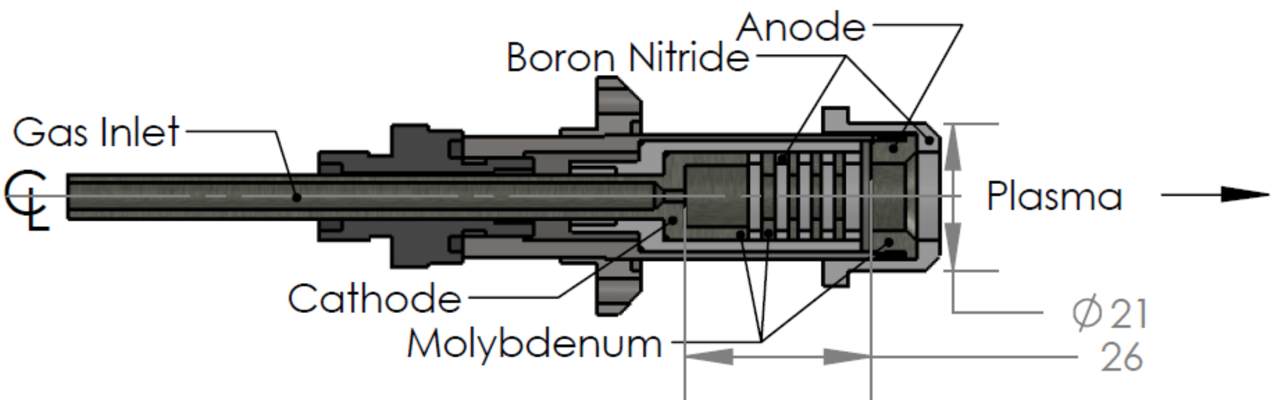
Experiment Overview

$B_z \approx 0.1T$
$I_P \approx 7kA$
$t \approx 20ms$
$a \approx 7cm$
$b, c = 7.5, 9.5cm$
$\tau_A \approx 1\mu s$
$\tau_{wall} \approx\ 7\,ms$

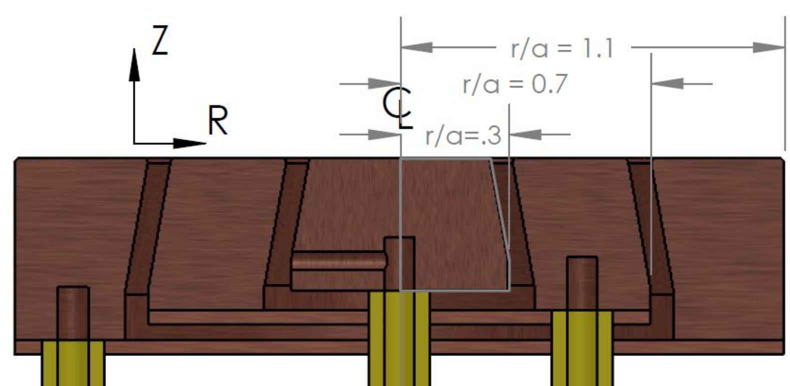
Magnetics:
80 $\tilde{B}_r$
30 $\tilde{B}_\theta$
10 $\tilde{B}_z$ coils



7 Plasma Gun Array



Segmented Anode Measures $J_z(r,t)$



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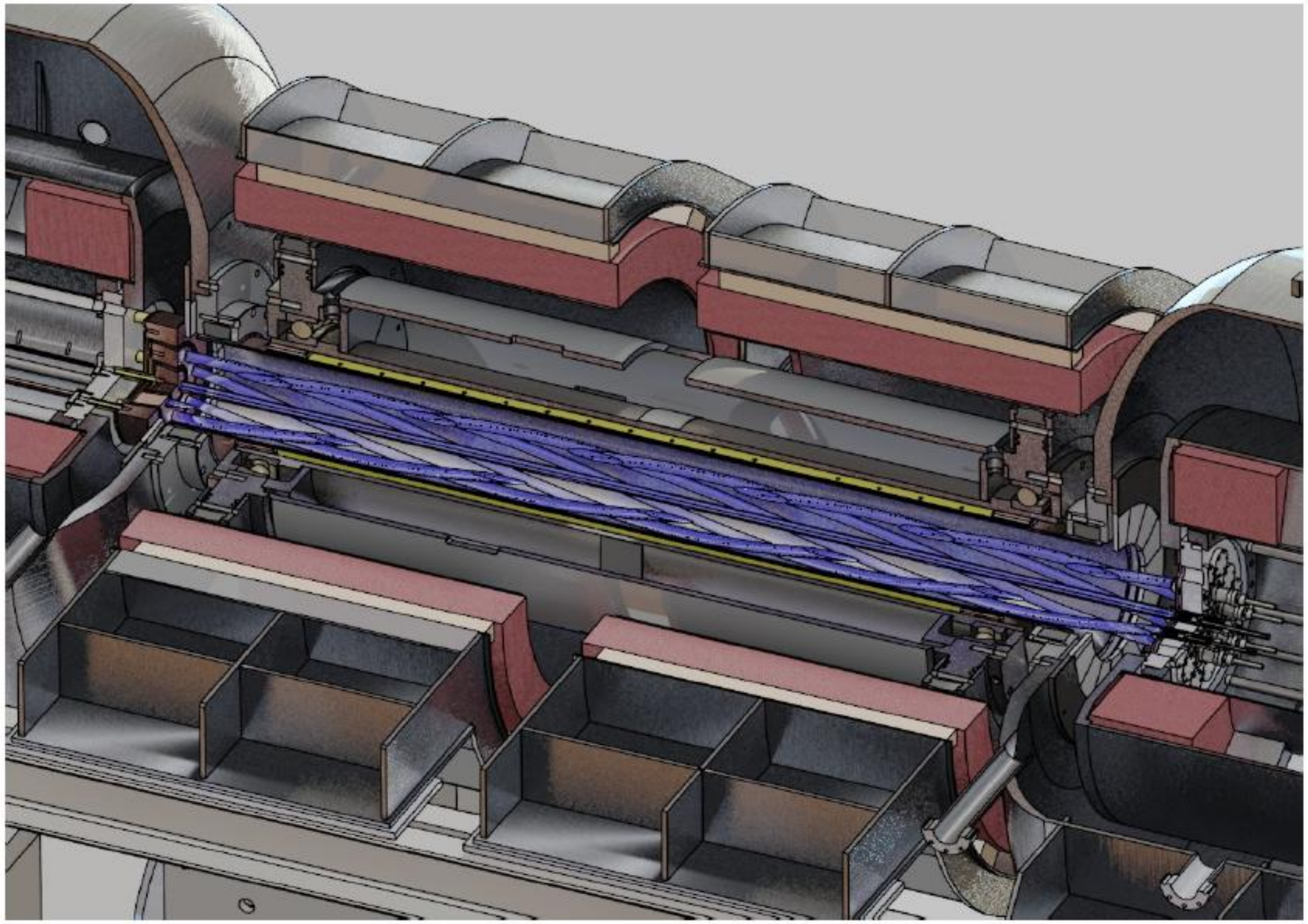

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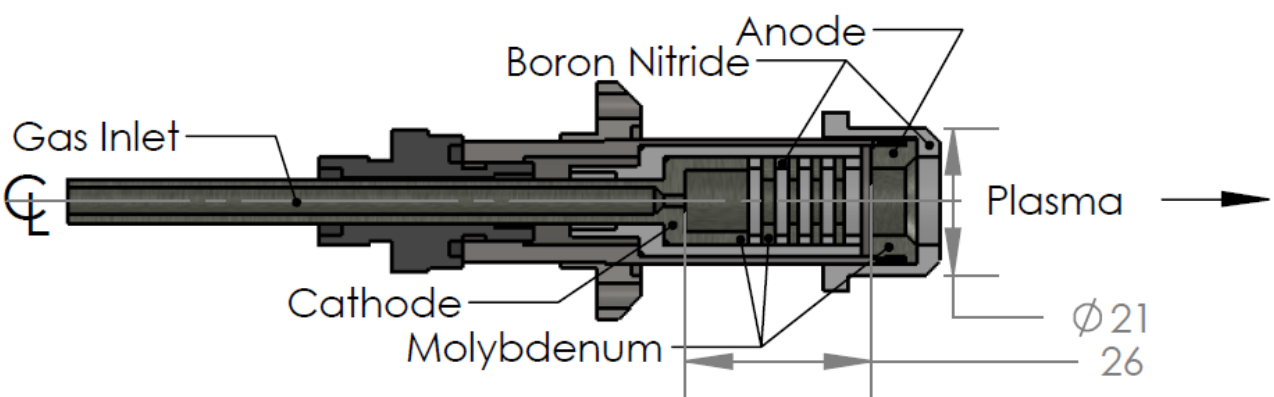

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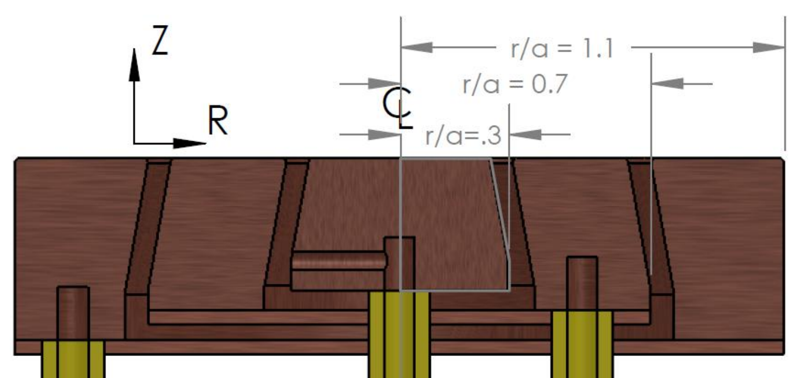
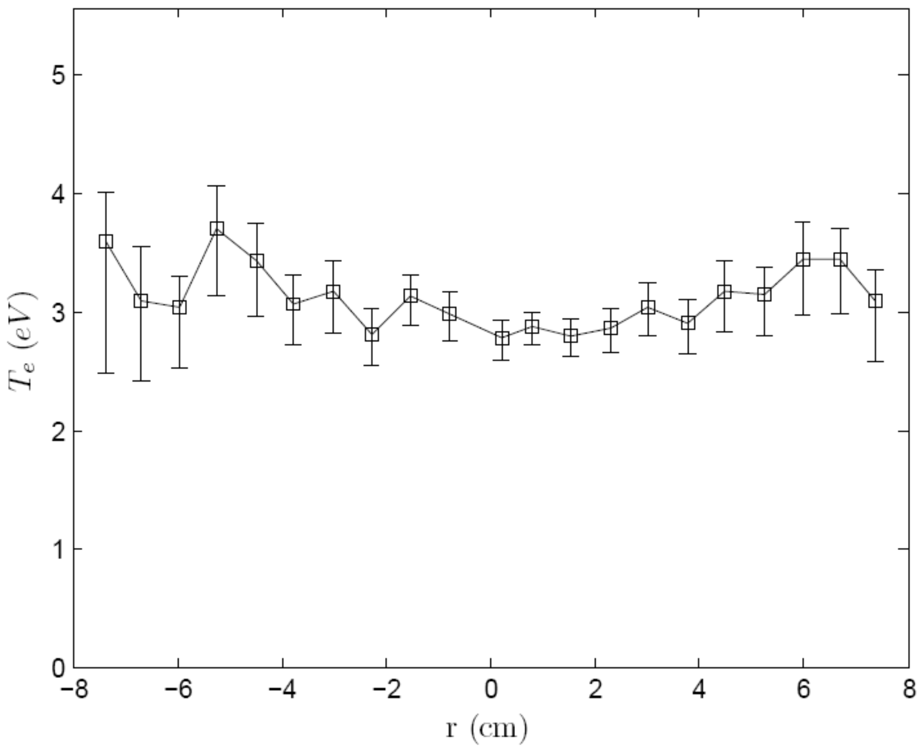
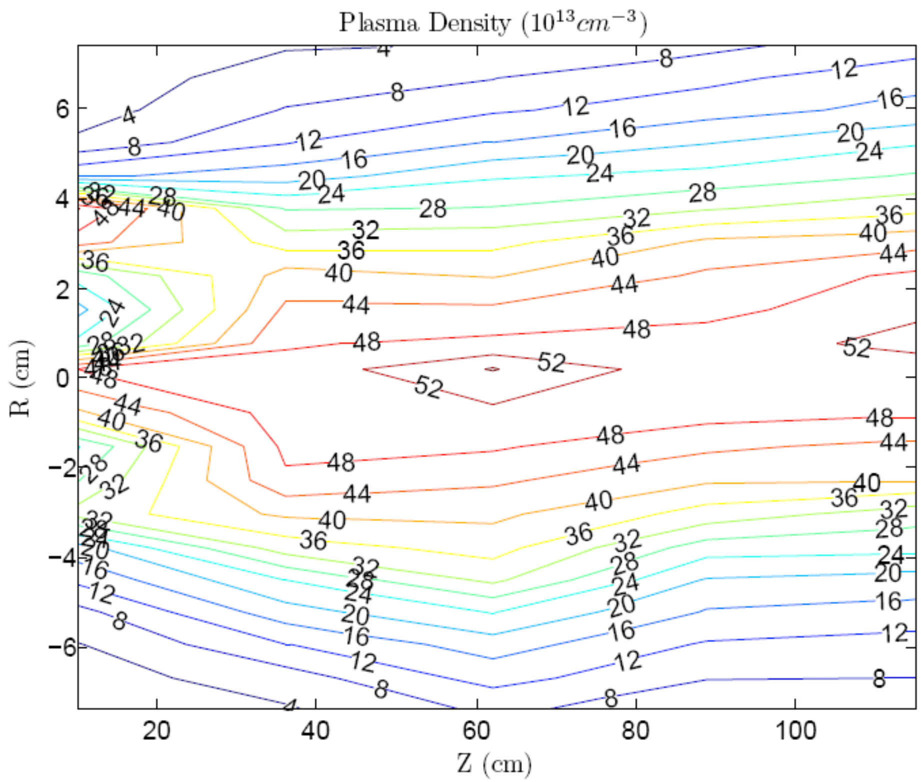


Plasma is Cold, Dense

- Langmuir Probe Results:
  - Temperature is cold, uniform
  - Density is large, well collimated
    - Increasing I_p raises density not temperature
  - Lundquist number $(t_{res}/t_A) \sim 30$
  - Data from a different configuration – qualitative only

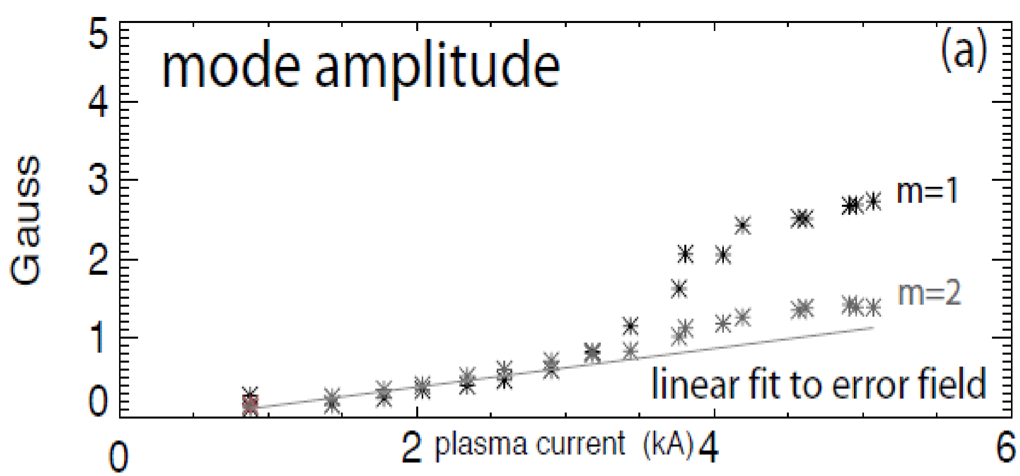


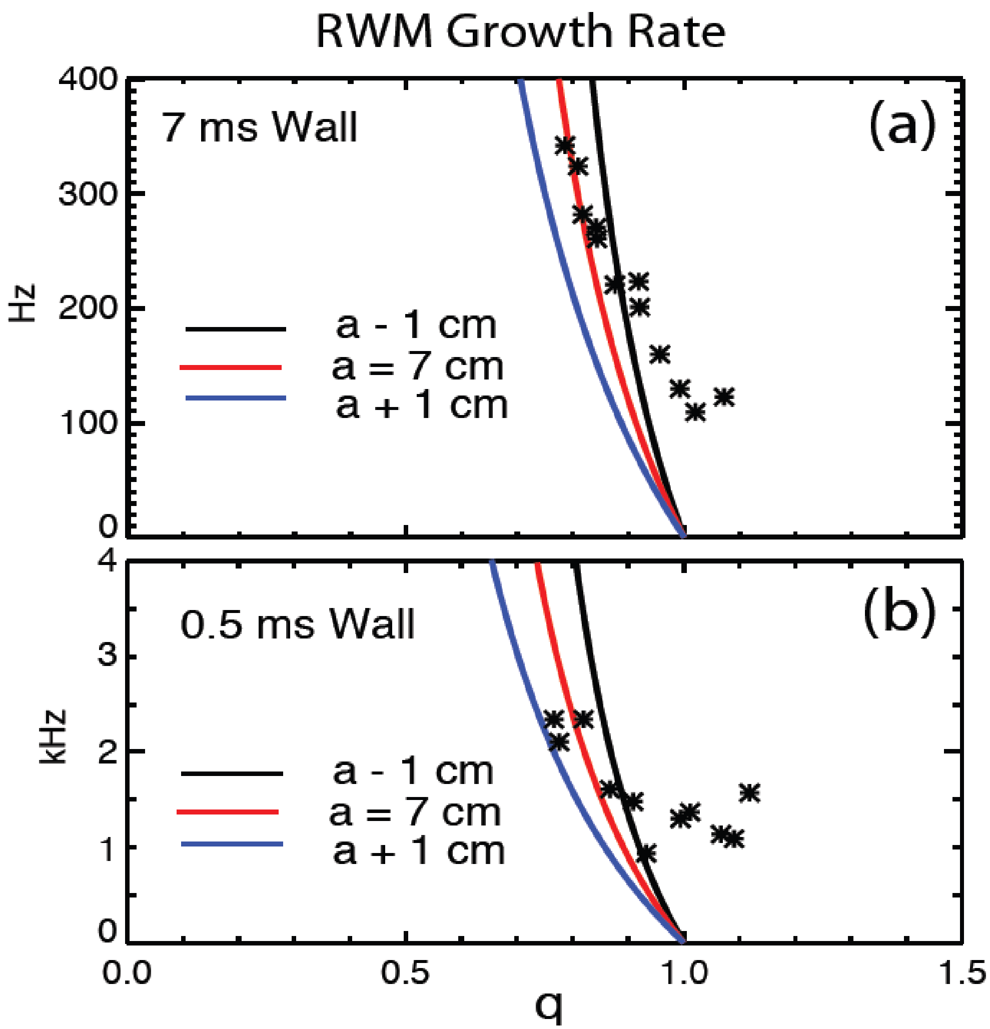


D.A. Hannum

RWM has been found in the Device

- Static Wall Results:
  - Mode found whose growth rate increases with decreasing q
  - Growth rate scales with wall time
  - Mode is obscured by an error field that must be subtracted





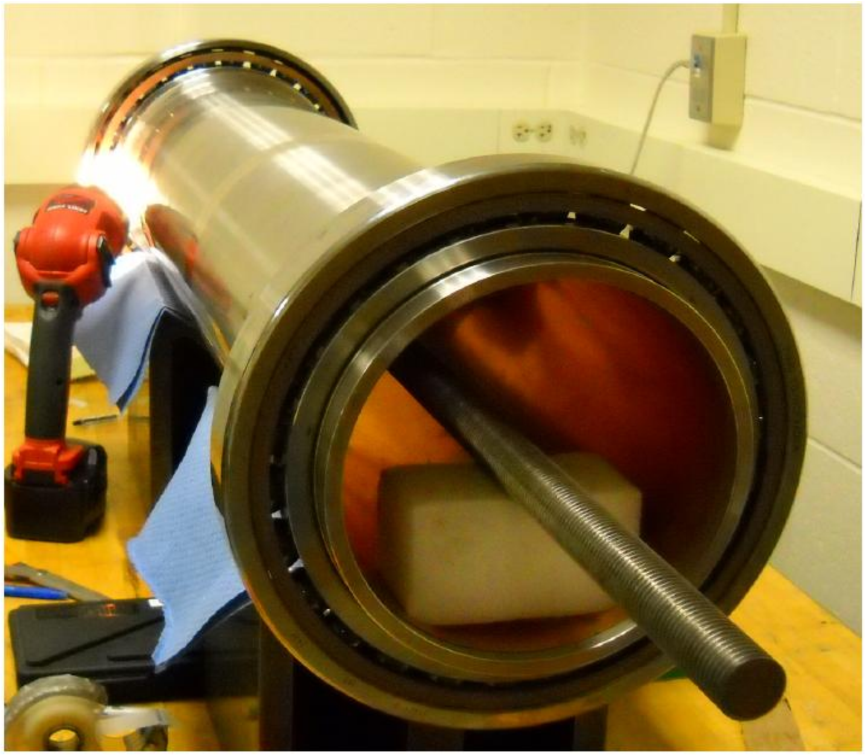
W.F. Bergerson, PhD Thesis

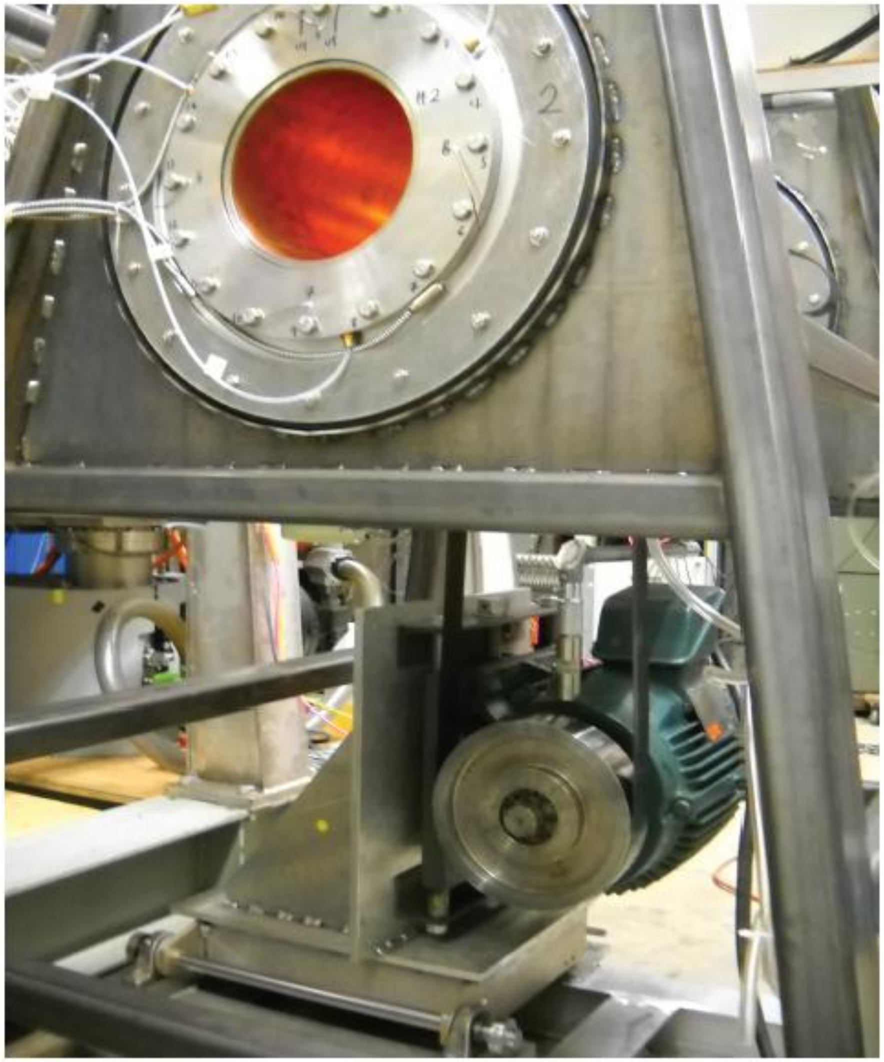
High Speed Rotating Wall has been Built

- Max kRPM = 8 ~ 280 km/h
- r=10 cm, L=1 m
- 10 kW motor belt drive
- 1 mm Cu + 1 cm 304SS
- 1 kRPM ~ .75 R_m
- t_w ~ 7 ms

$$\frac{\partial}{\partial t}\vec{B} = \nabla \times \vec{V} \times \vec{B} + \frac{\eta}{\mu_0}\nabla^2\vec{B}$$

$$R_m = \frac{\nabla \times \vec{V} \times \vec{B}}{\frac{\eta}{\mu_0}\nabla^2\vec{B}}$$

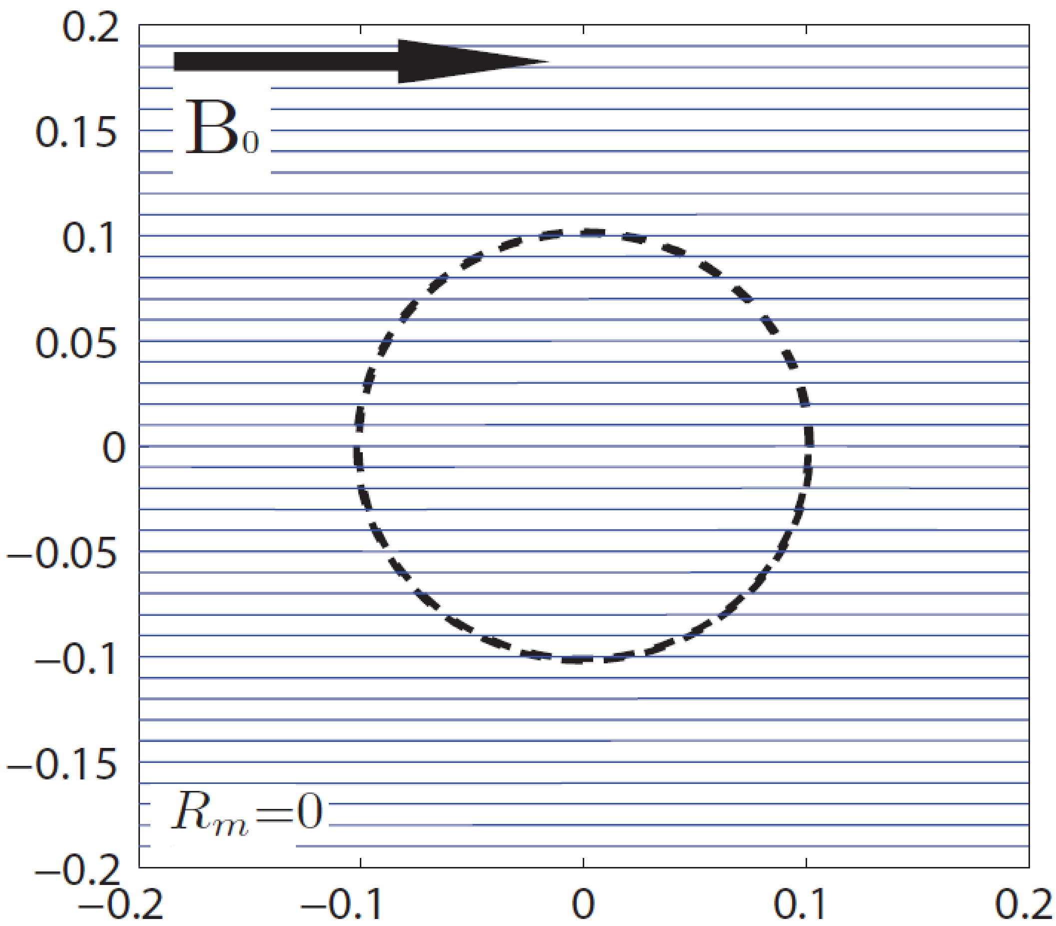


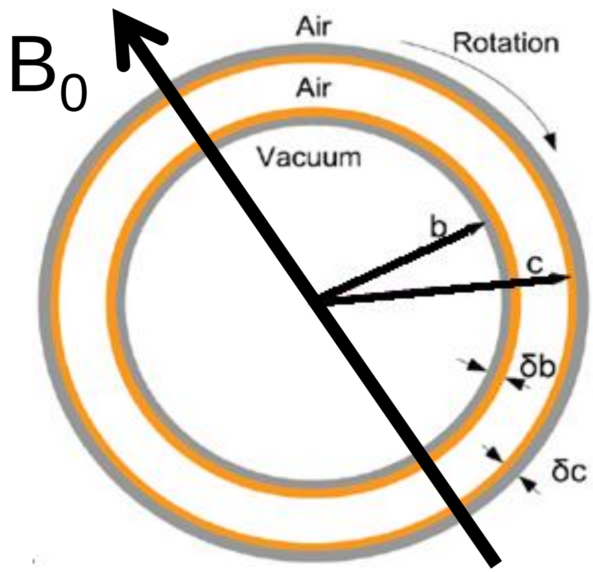


Wall in Test Stand Configuration

Vacuum Benchmark Performed

- Analytic Steady State Solution:

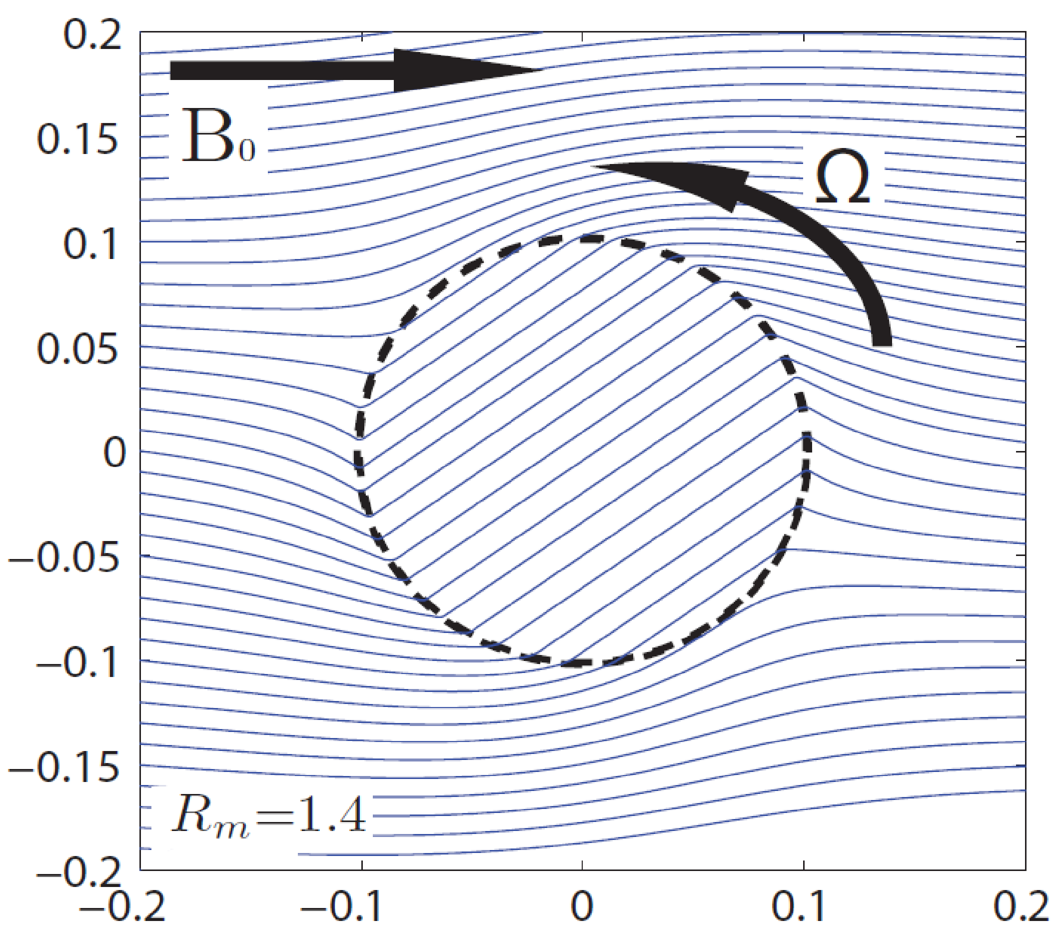


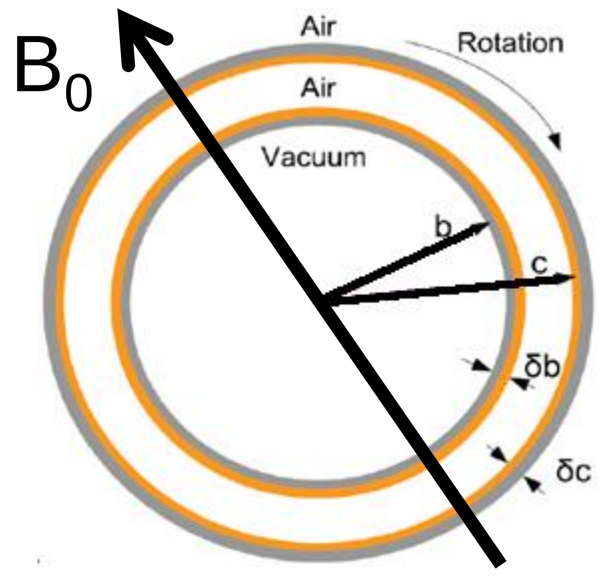


(No plasma)

Rotating Wall Advects and Excludes Flux

- Analytic Steady State Solution:





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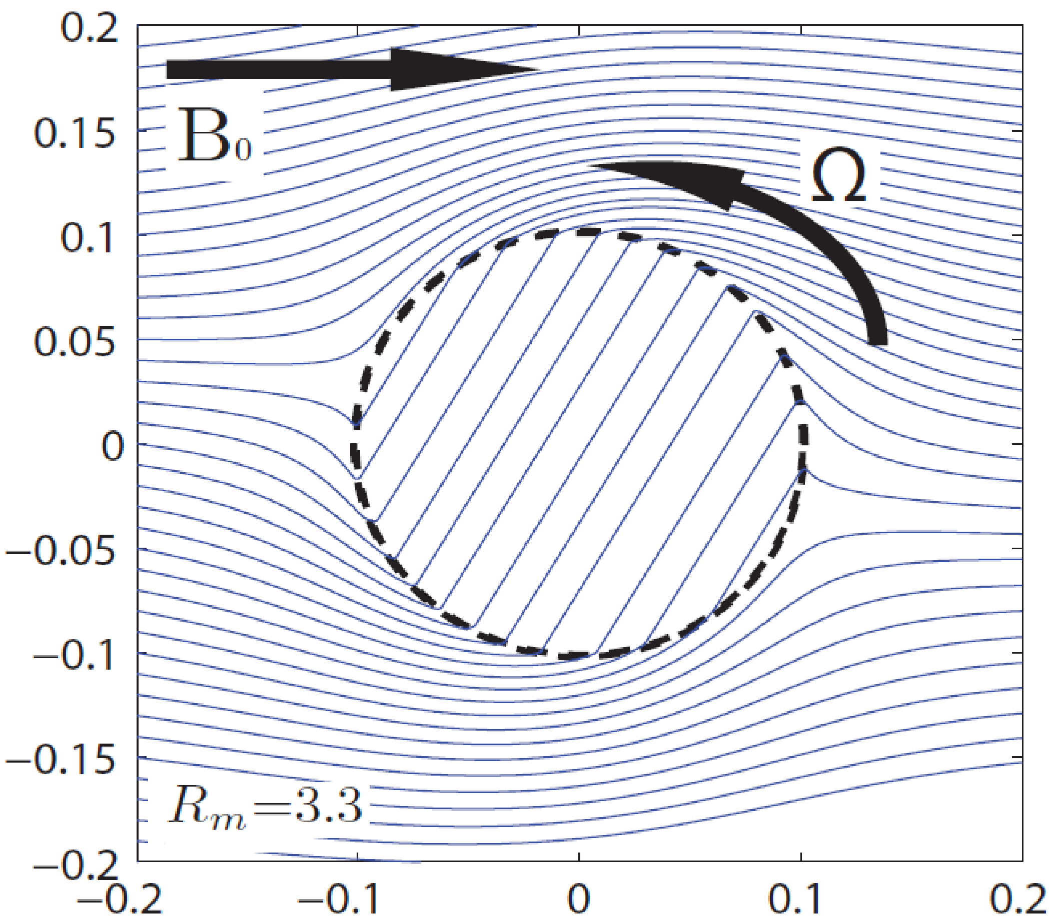
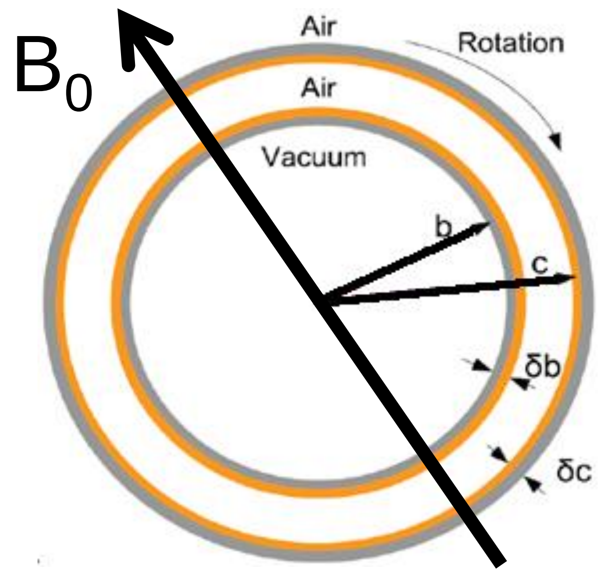
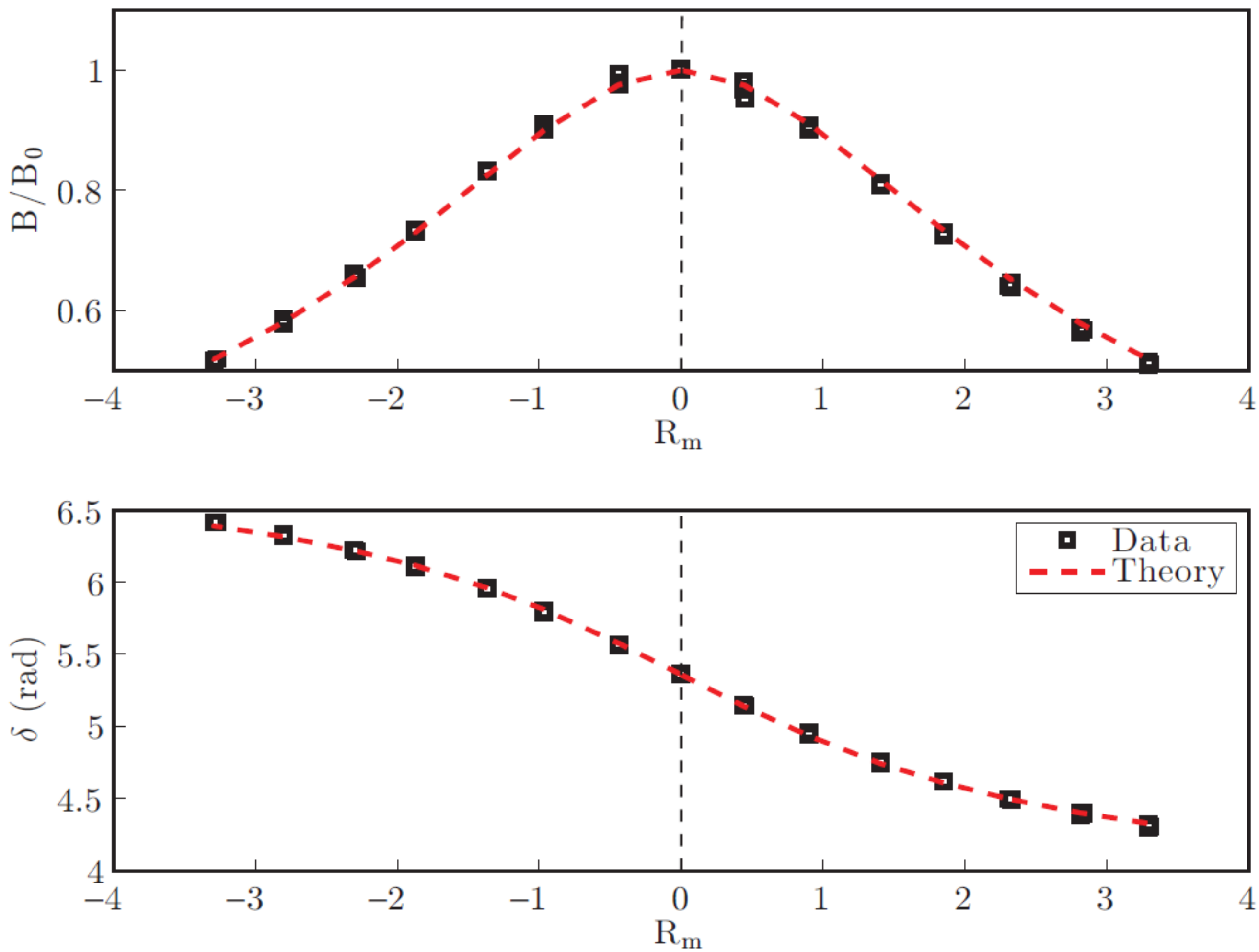




- Observations:
  - Less magnetic field inside wall as rotation is increased
  - Response is out of phase from original field
  - Phase shift asymptotes to pi/2

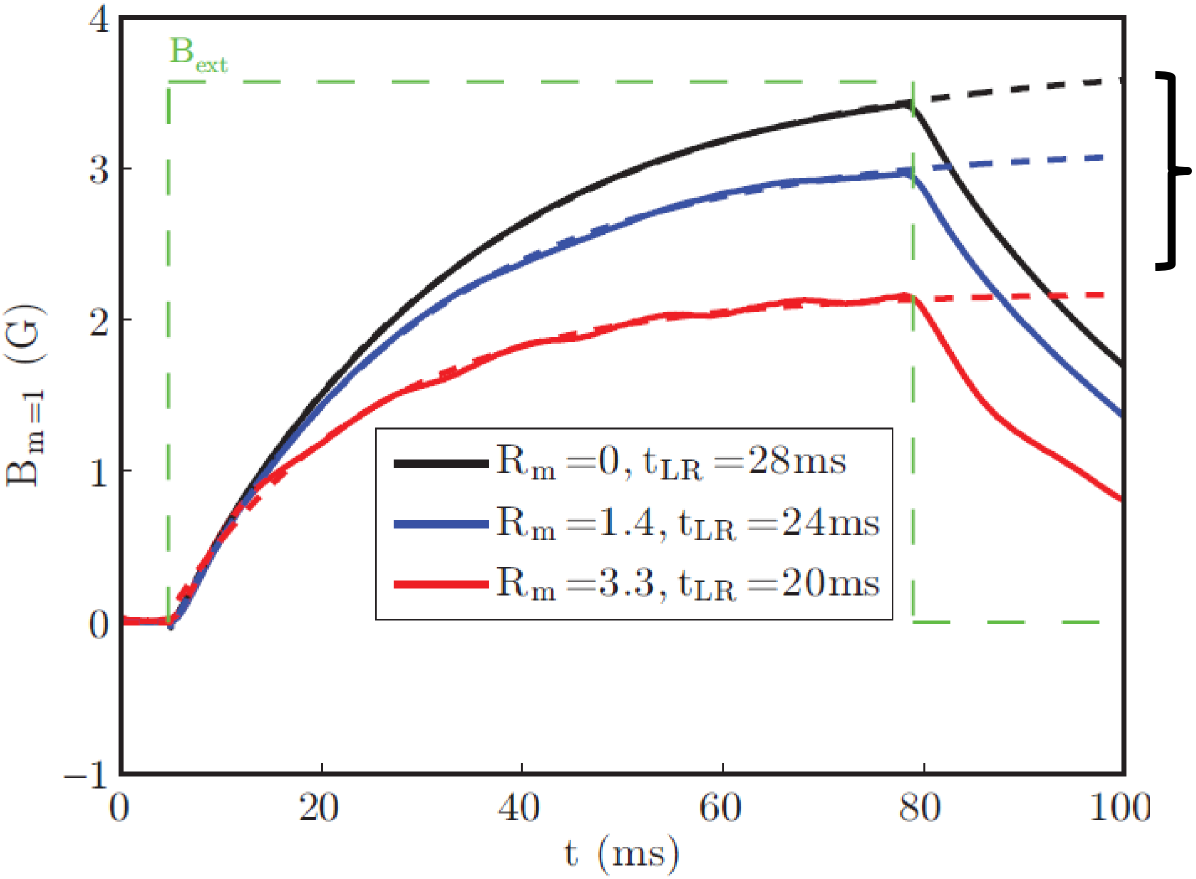
Result Applies to External Error Fields

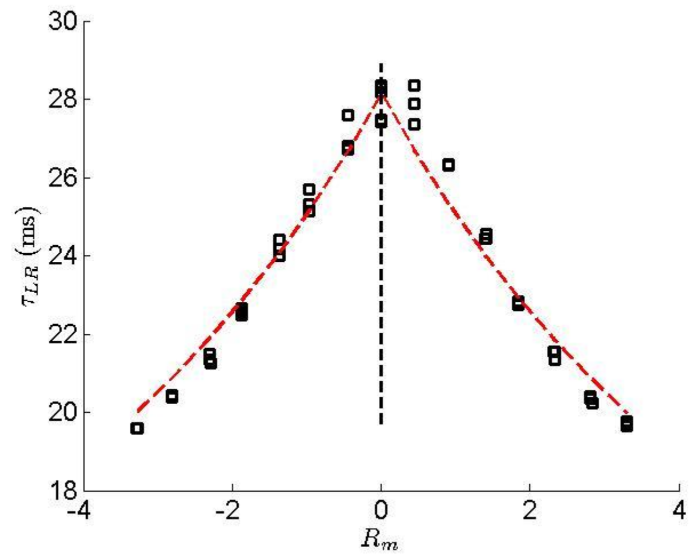
- External error fields are *permanently* shielded by rotating wall
- Internal fields are phase shifted by advection
- Results in excellent agreement with theory (R_m well known)



Rotating Wall Varies Effective LR Time

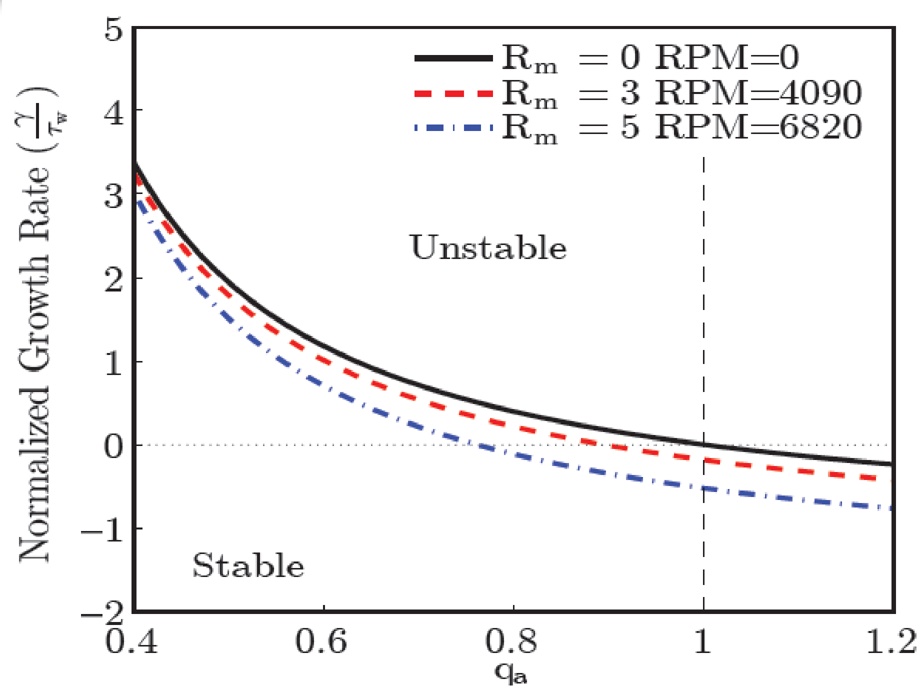
- Vertical field penetration time decreased
  - Match to analytic model still forthcoming

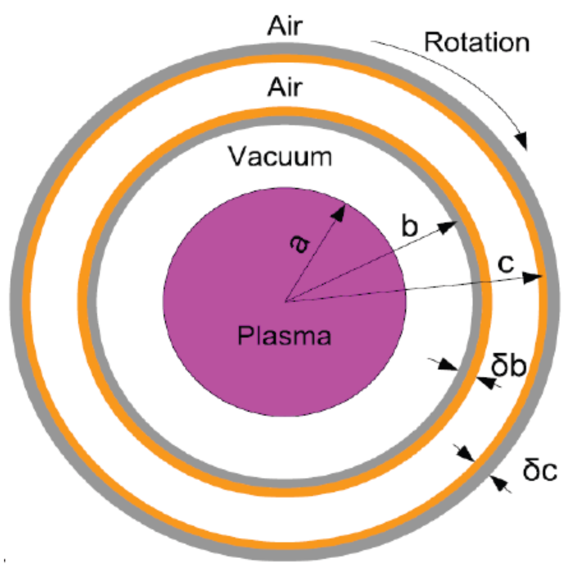


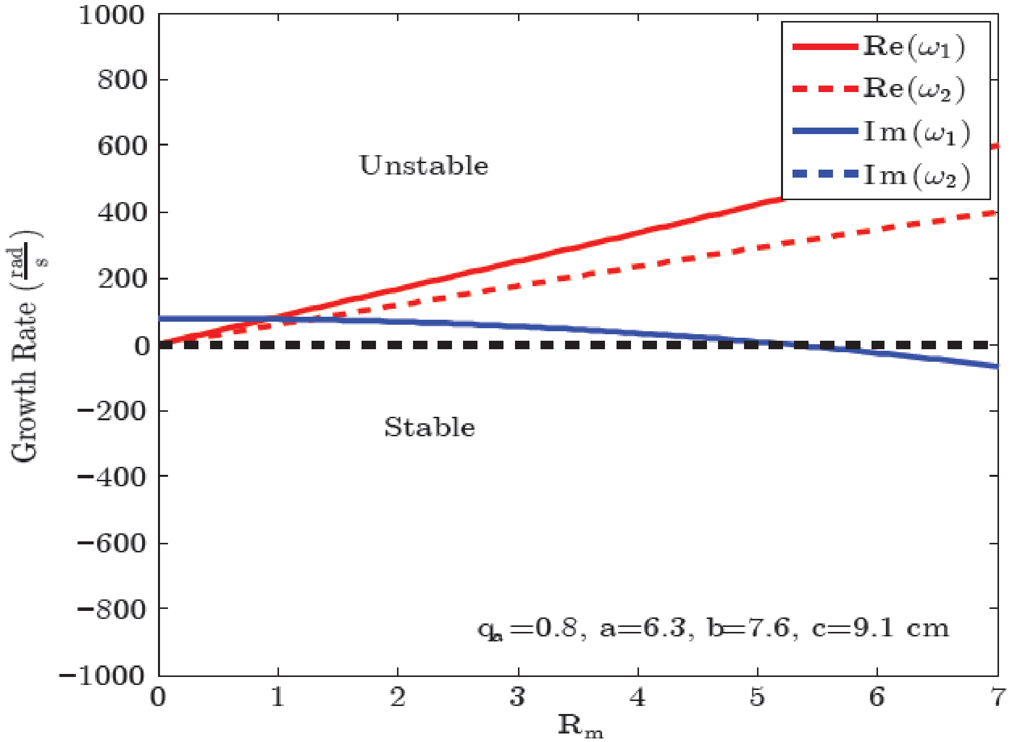


Theory Predicts Rotating Wall Stabilizes RWM

- Linear, force free, incompressible, ideal MHD predictions show RWM stabilization for large R_m



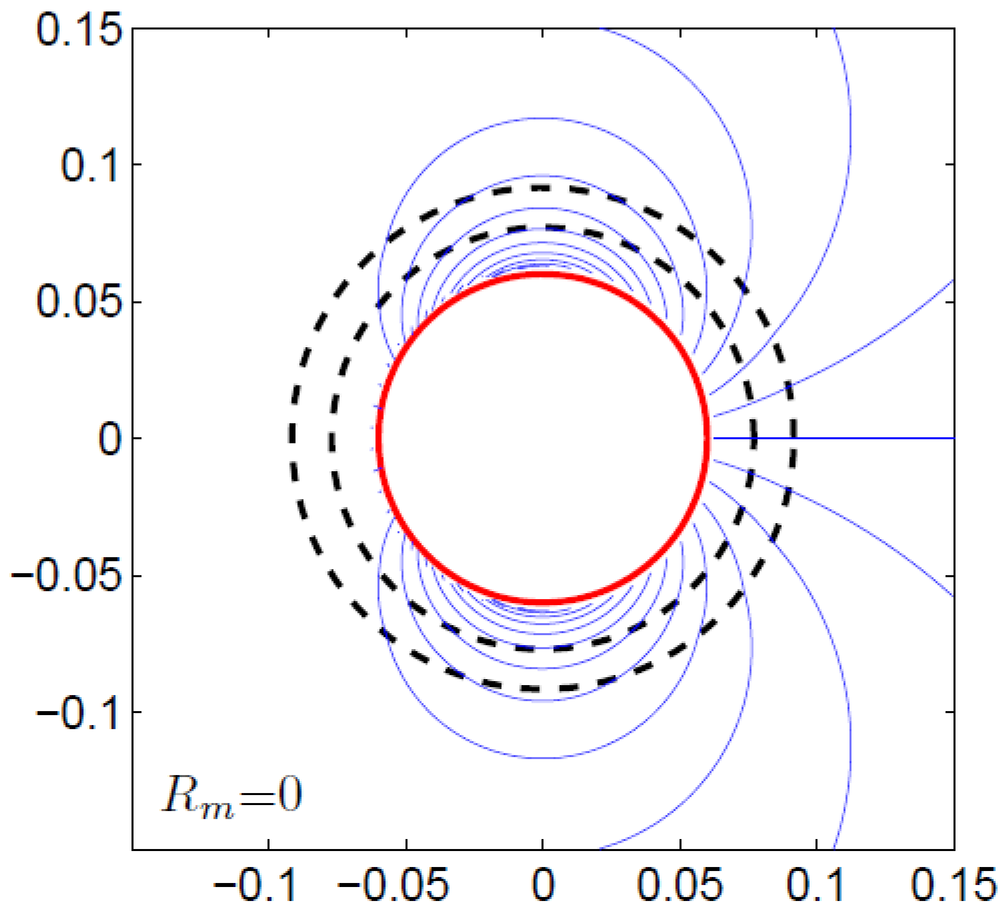


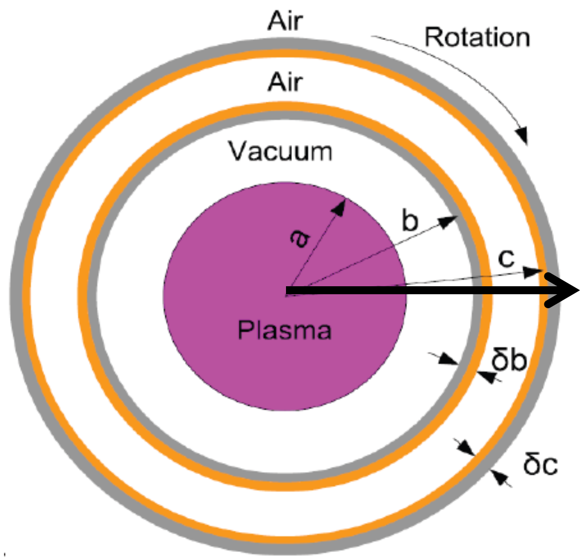


C.C. Hegna, Phys. Plasmas **11**, 4230 (2004).

Rotating Wall Advects and Excludes Flux

- Theoretical RWM Eigenfunction (Vacuum Part)
  - $B(r,\theta)\, e^{\gamma t}$





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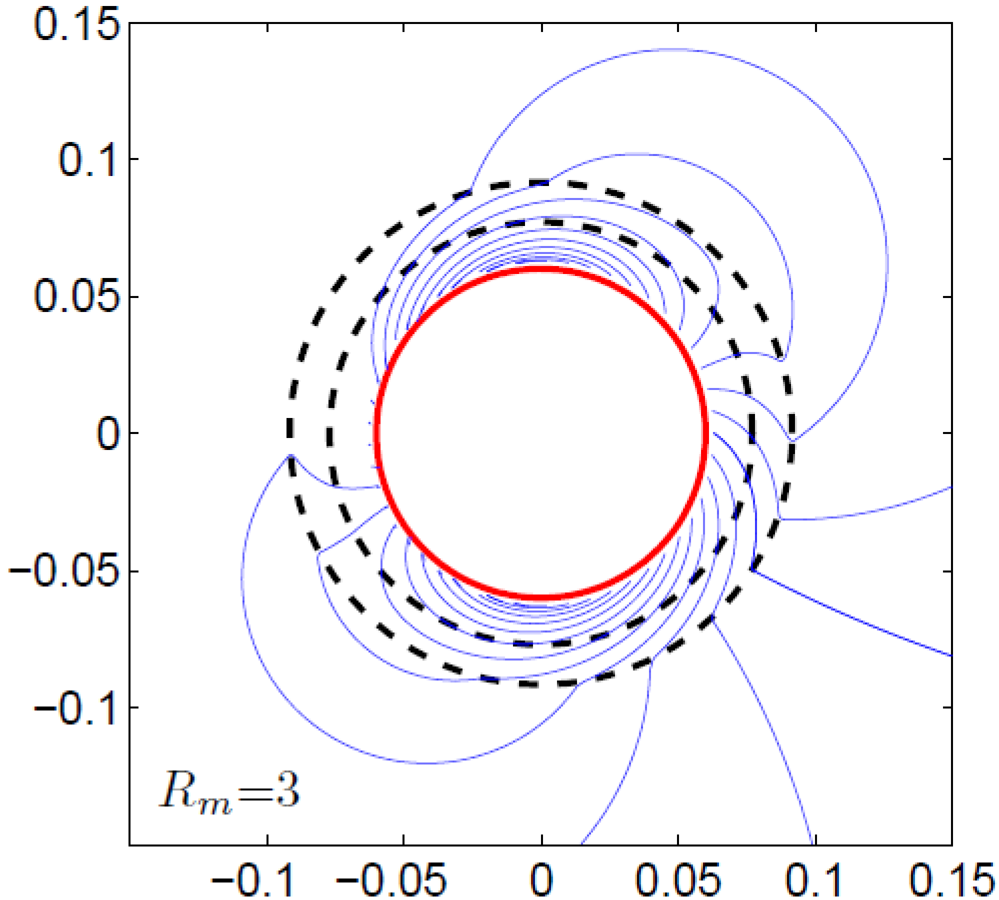

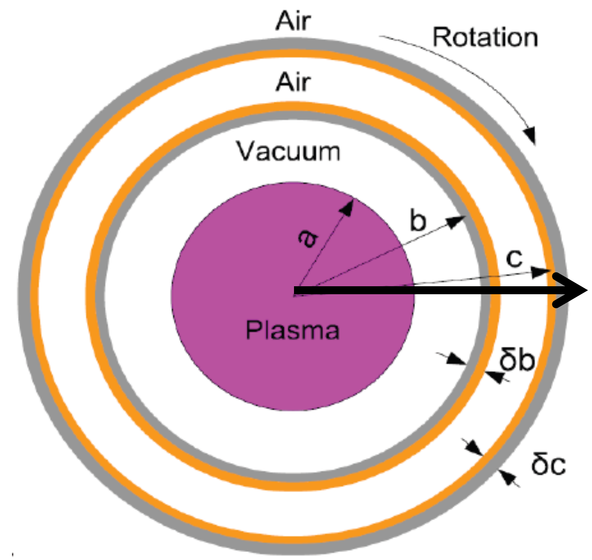

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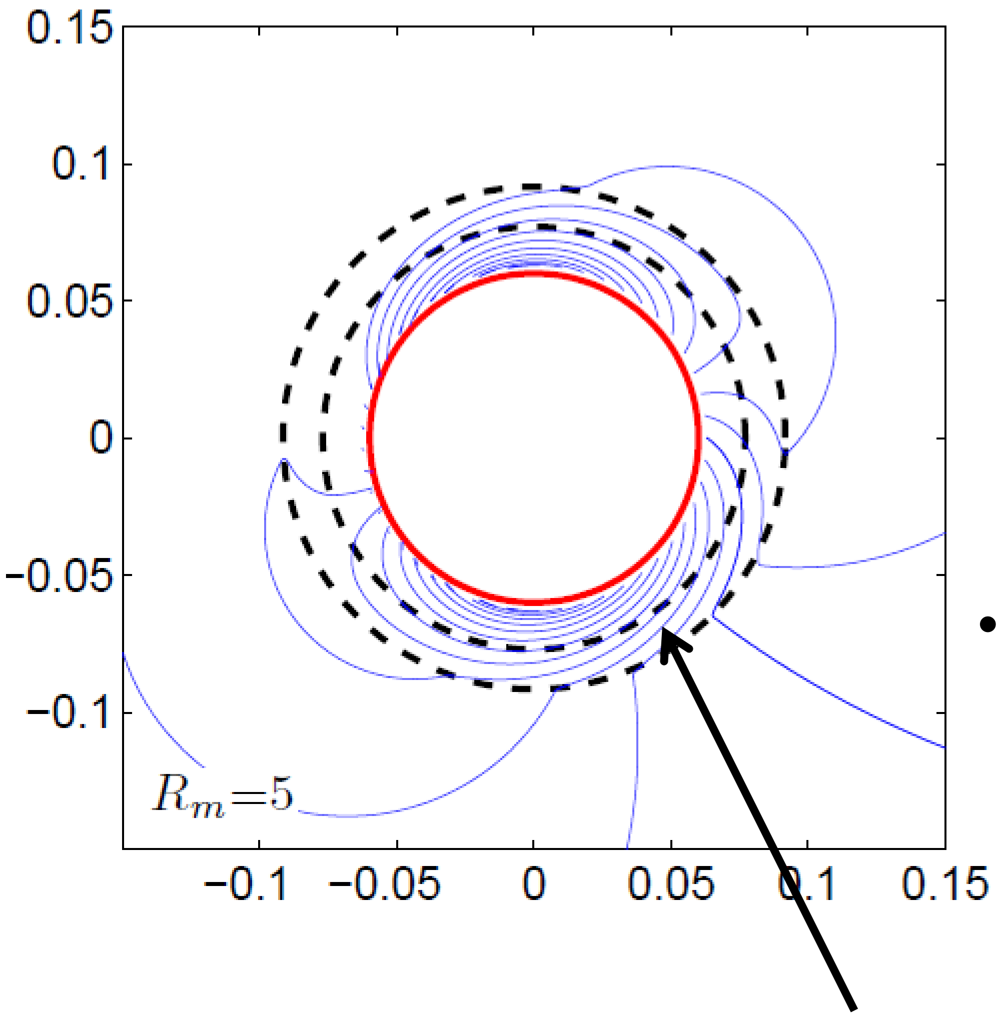
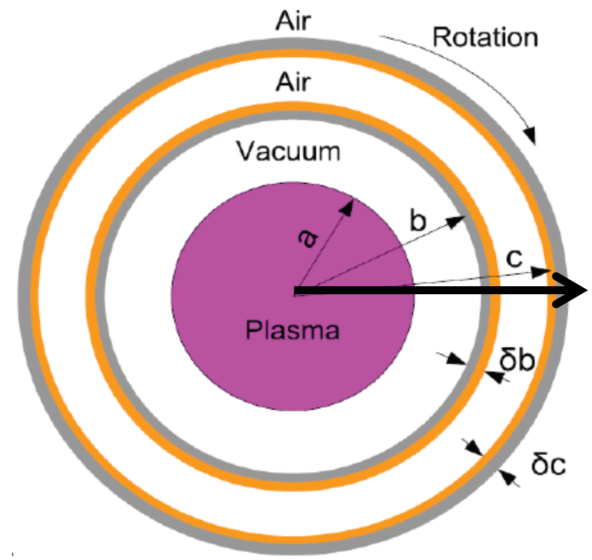


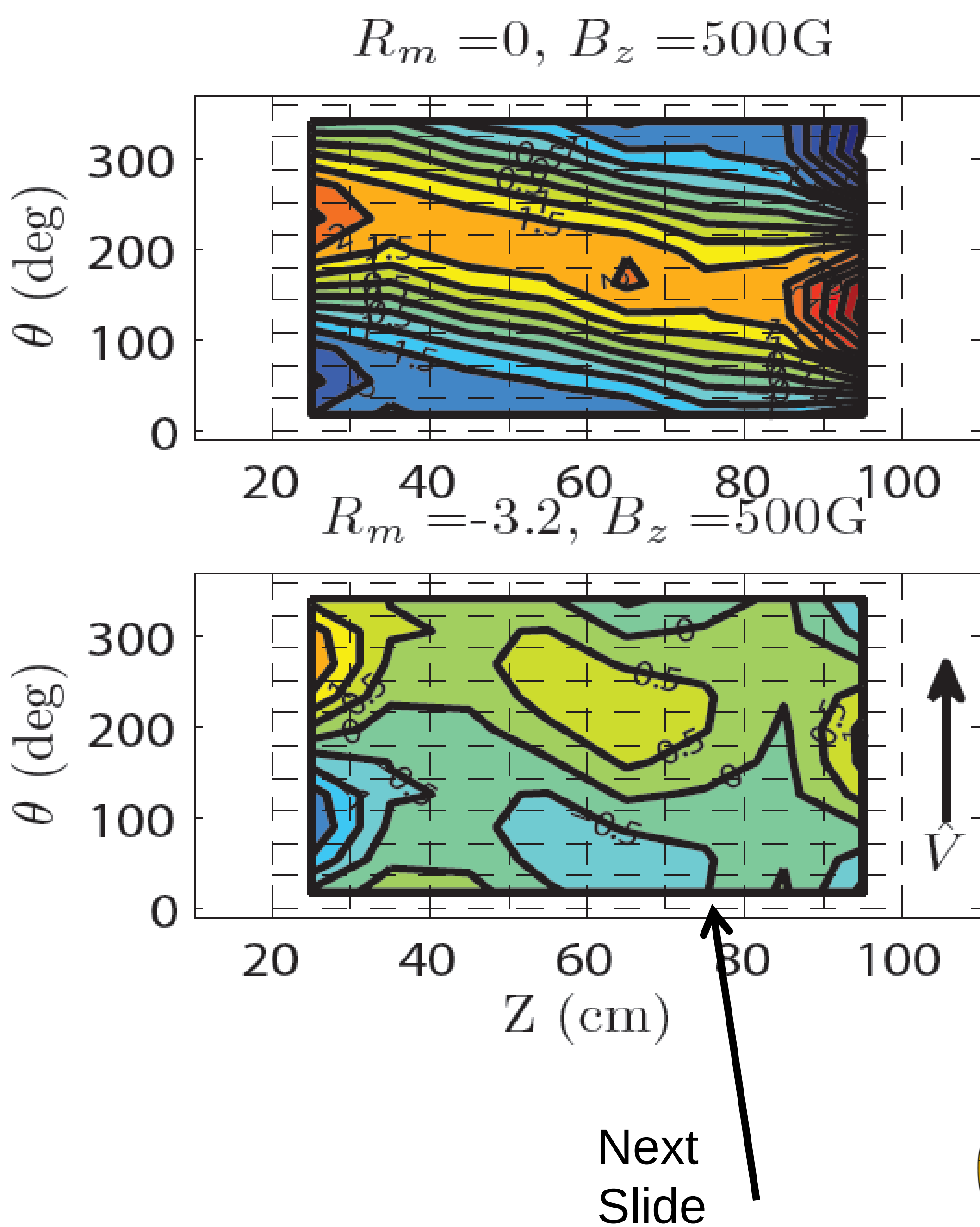


- Observations:
  - Field is kept inside by rotation
  - Out of phase response should rotate mode signature

Reminder: we measure B_r in-between the walls with an 8x10 fluxloop array

Preliminary Results Suggest RWM Stabilization

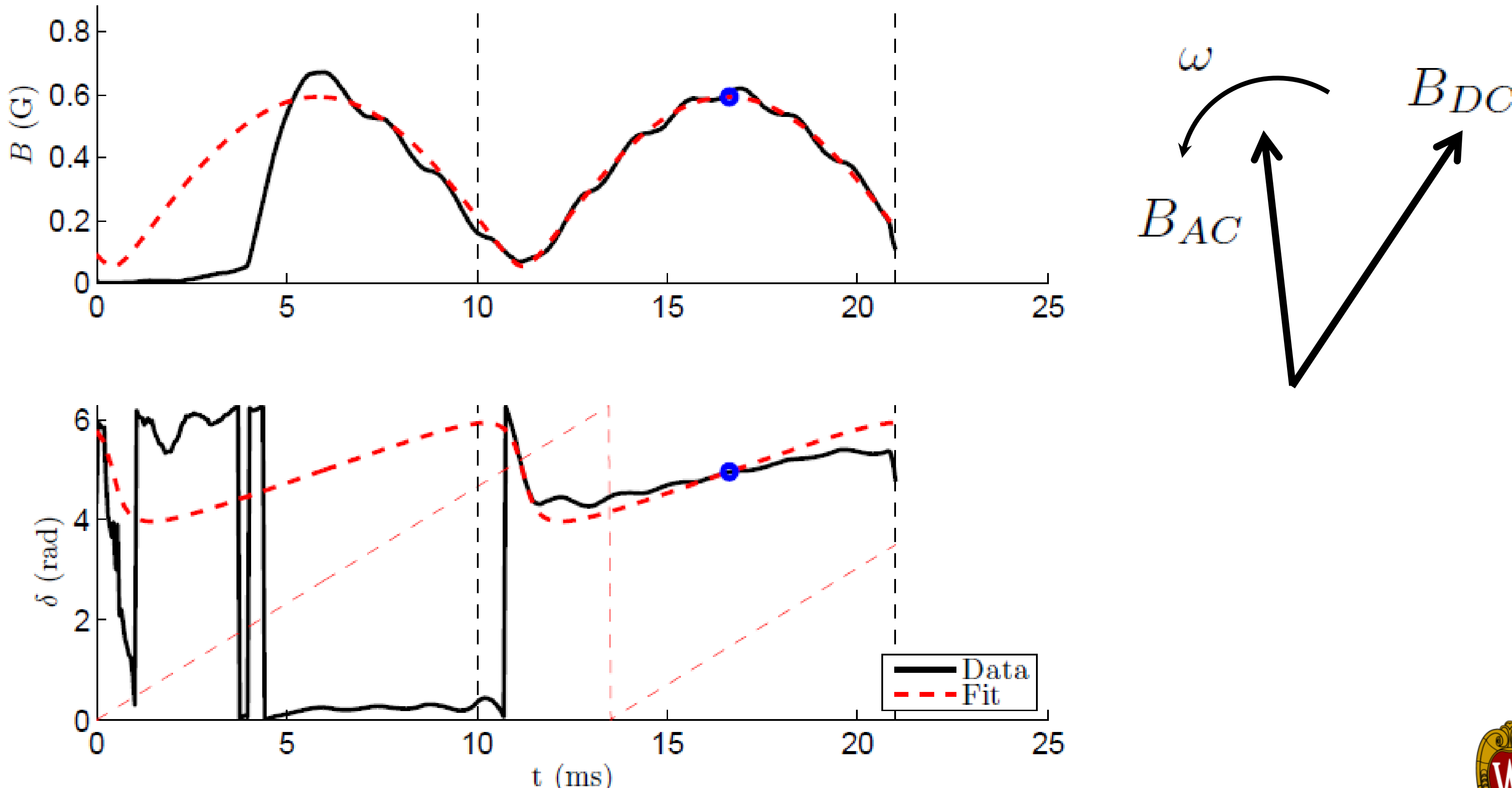
- Contour plot of B_r mode signature from 8x10 fluxloop array shown
- Rotation can clearly reduce B_r amplitude to error-field levels
- Greatest effect seen near midplane-anode
- Suggests RWM stabilization
- Field near cathode (z=0 cm) relatively unaffected



Stabilized RWM Shows Cycloidal Behavior

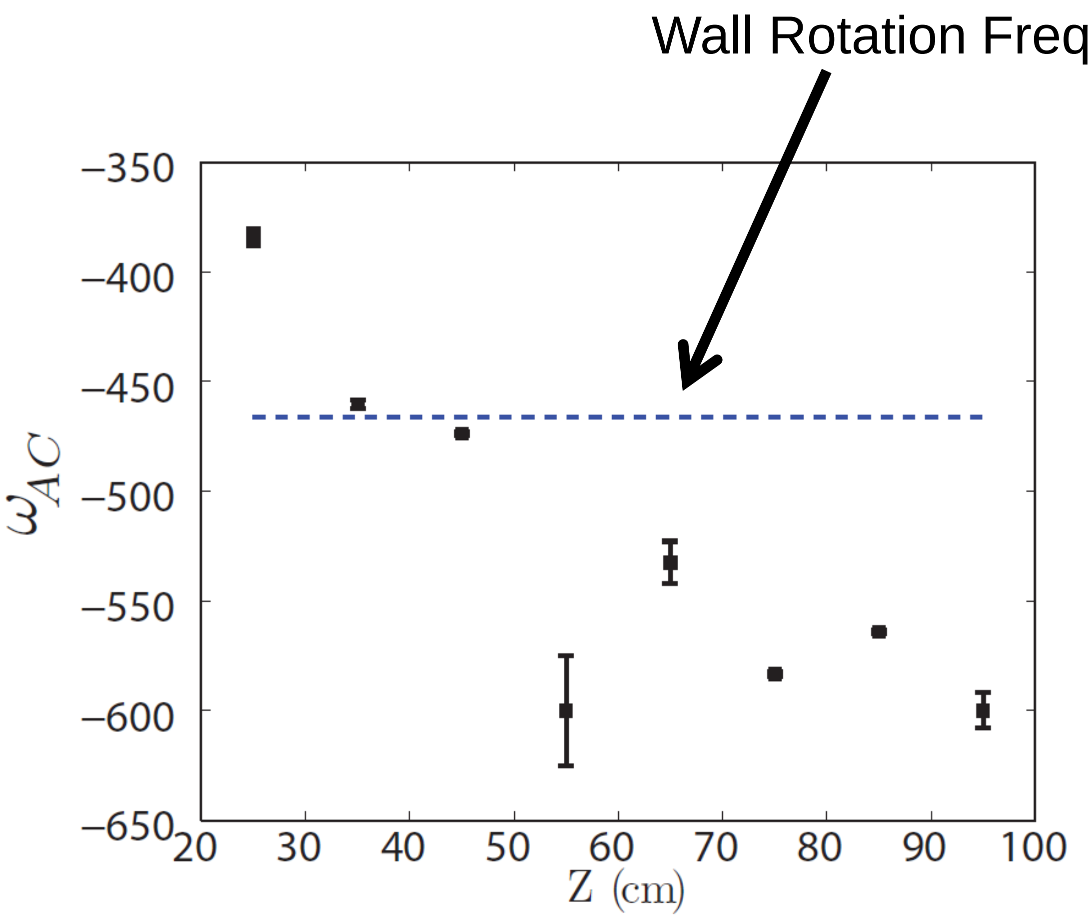
- Fourier decomposition isolates m=1 component at a fixed axial location
- B_r behavior matched well by AC + DC fields beating together, yielding cycloids
- AC field not observed in static wall case

$$B(\theta,t) = B_{DC}\cos\left(m\theta - \delta_{DC}\right) + B_{AC}\cos\left(m\theta - \omega t - \delta_{AC}\right)$$



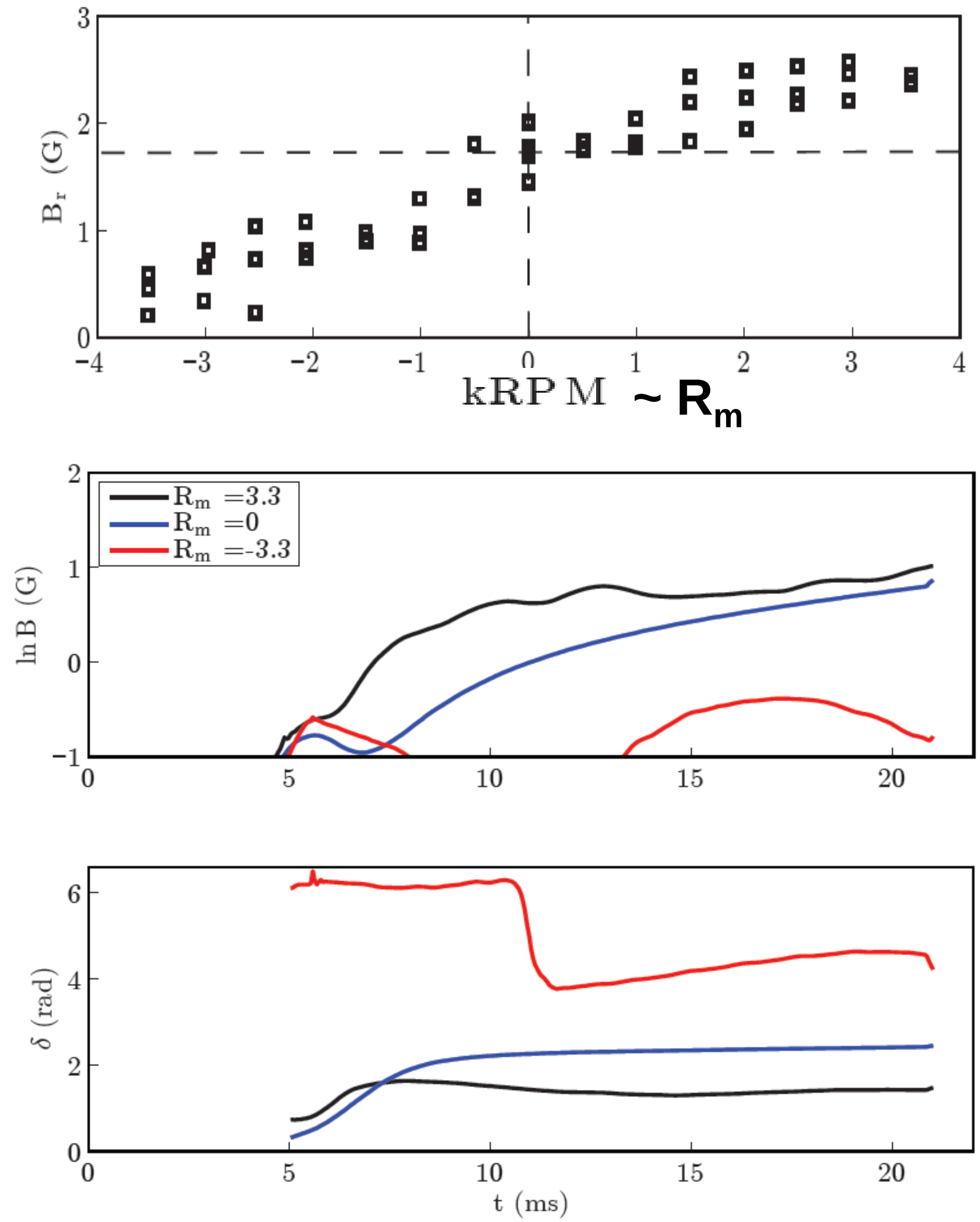
Frequency is above wall rotation

- Wall rotation appears to have created a rotating mode rotating faster than the wall
- Clearest cycloids (best fits) seen at B_{DC} minimums, near anode of experiment



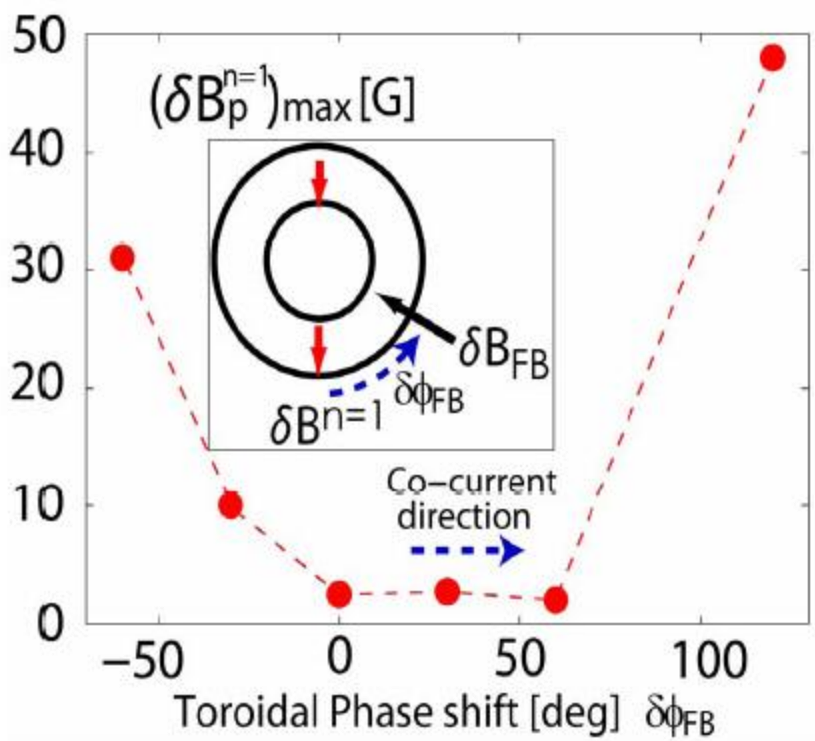
Asymmetry in Rotation Direction Observed

- One rotation direction appears to be destabilizing, the other stabilizing
- May indicate plasma rotation
- Yet, magnetic signature is locked in unstable case
- Not yet fully understood



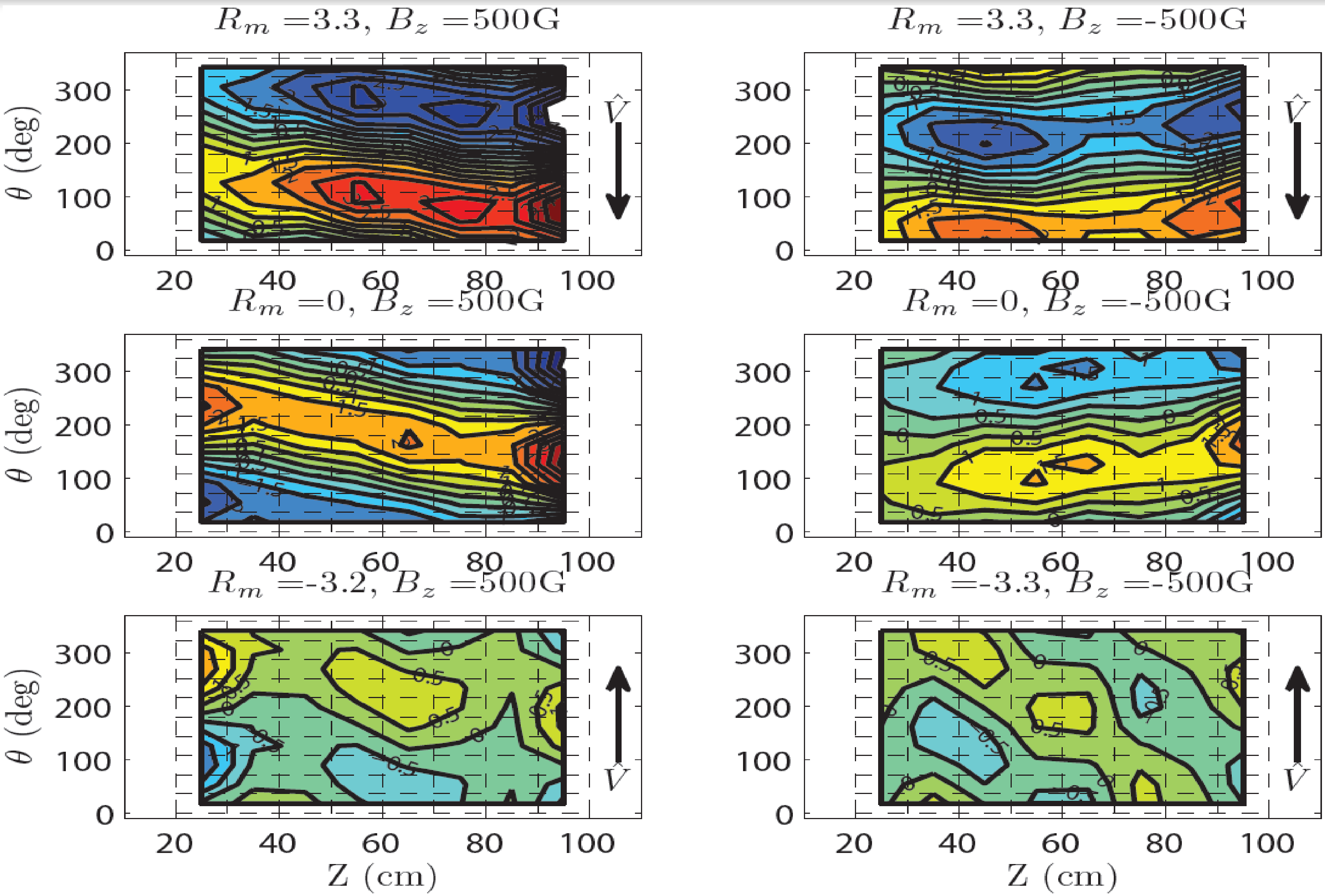
Feedback phase matters

- Phase of rotating wall response shifts from +90 to -90 depending on rotation direction (recall B_{ext} response)
- Asymmetry result similar to that of DIII-D
- May hint at similar mechanisms



Y. In, MHD Workshop ‘09

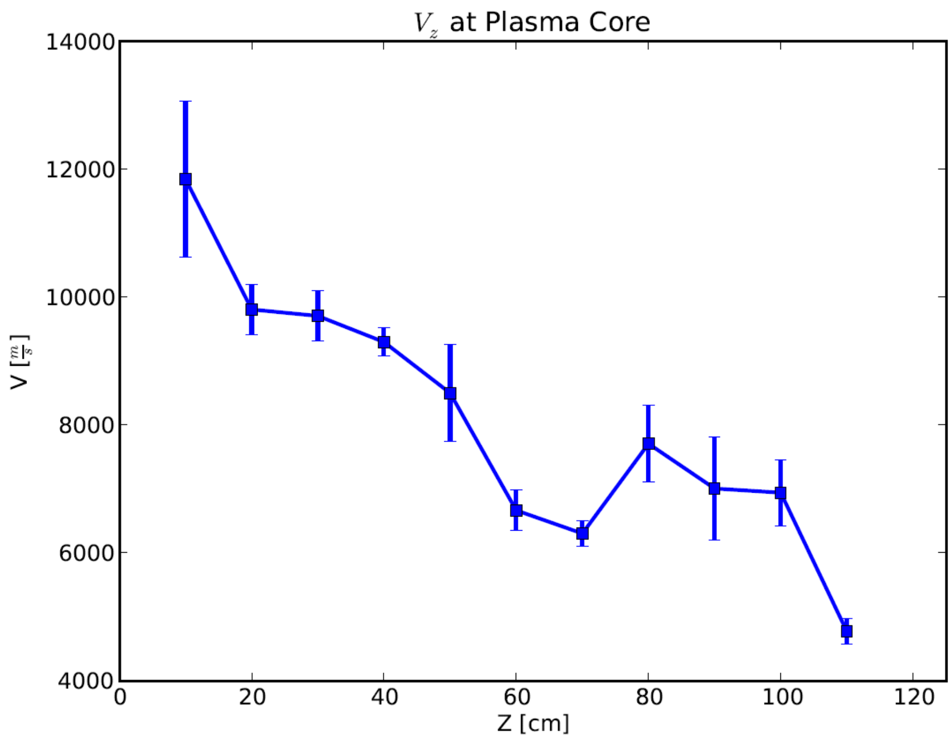
Asymmetry Insensitive to B_z Reversal

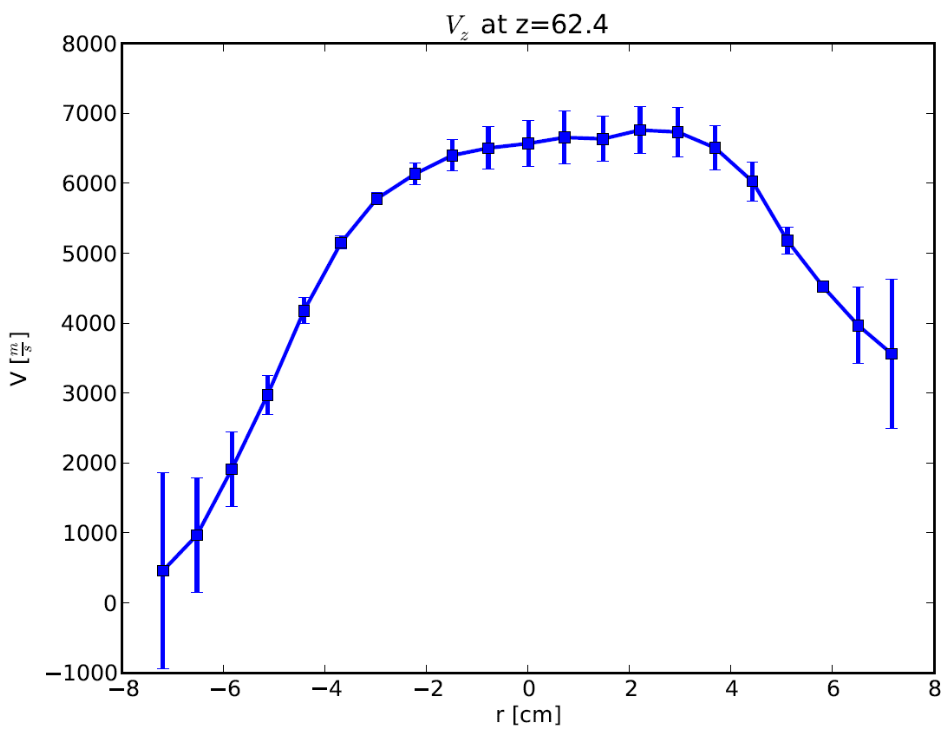


- Mode helicity seen to reverse
- Phase advection insensitive to Bz

Flows can break symmetry

- Axial flow may be breaking symmetry
- Large axial flows known to exist in plasma due to plasma gun
- Work to be done quantifying role of flow in our geometry
- Axial current direction was not reversed either





Conclusion & Future Work

- Conclusions:
  - Main experimental apparatus – the Rotating Wall – is built and functional
  - Vacuum tests show field exclusion and rotation
  - Plasma appears to be stabilized for large R_m
  - Asymmetry in rotational stabilization observed
- Future Work:
  - These are recent results – much yet to be done.
  - Characterization of error field time-dynamics during rotating wall discharges
  - Fit and separate AC and DC components and see trends with RPM, q, B_z
  - Further investigation of asymmetry

Questions?

Tour of Experiment at 6pm Tuesday